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(54) Method and apparatus for inspecting a crystalline object

(57) A gamma diffractometer for examining objects from the materials aspect, more particularly for inspecting monocrystal blades for turbomachines by Roentgen radiation, and evaluation of radiation reflections with regard to their half width and spacing comprises a radioactive source 1 surrounded by a lead shield 2. A collimator 4 directs gamma radiation onto a turbine blade 6 rotating on a turntable 7. The intensity of diffracted radiation is picked-up by a stationary detector 8 and displayed on a screen 11.

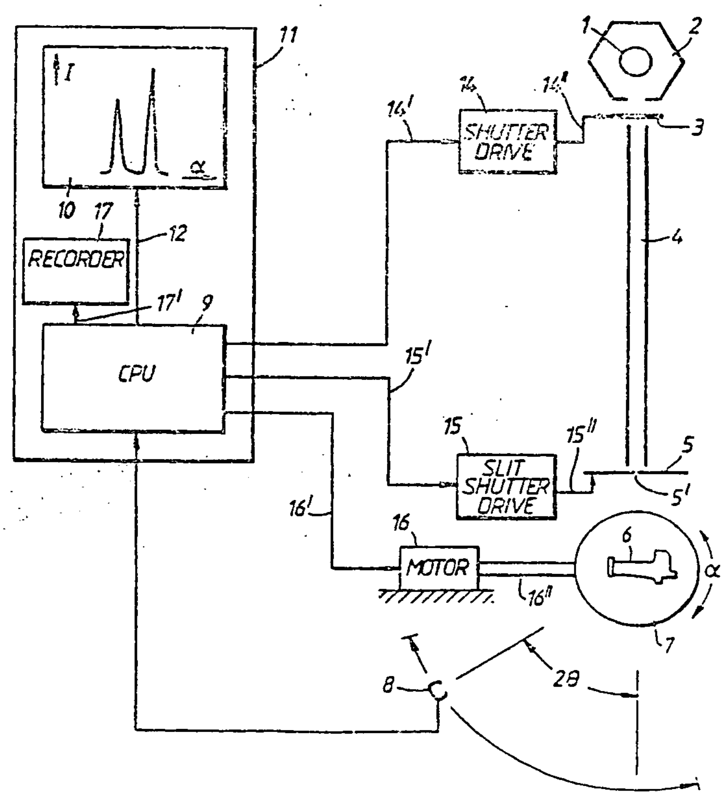

FIG. 1.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

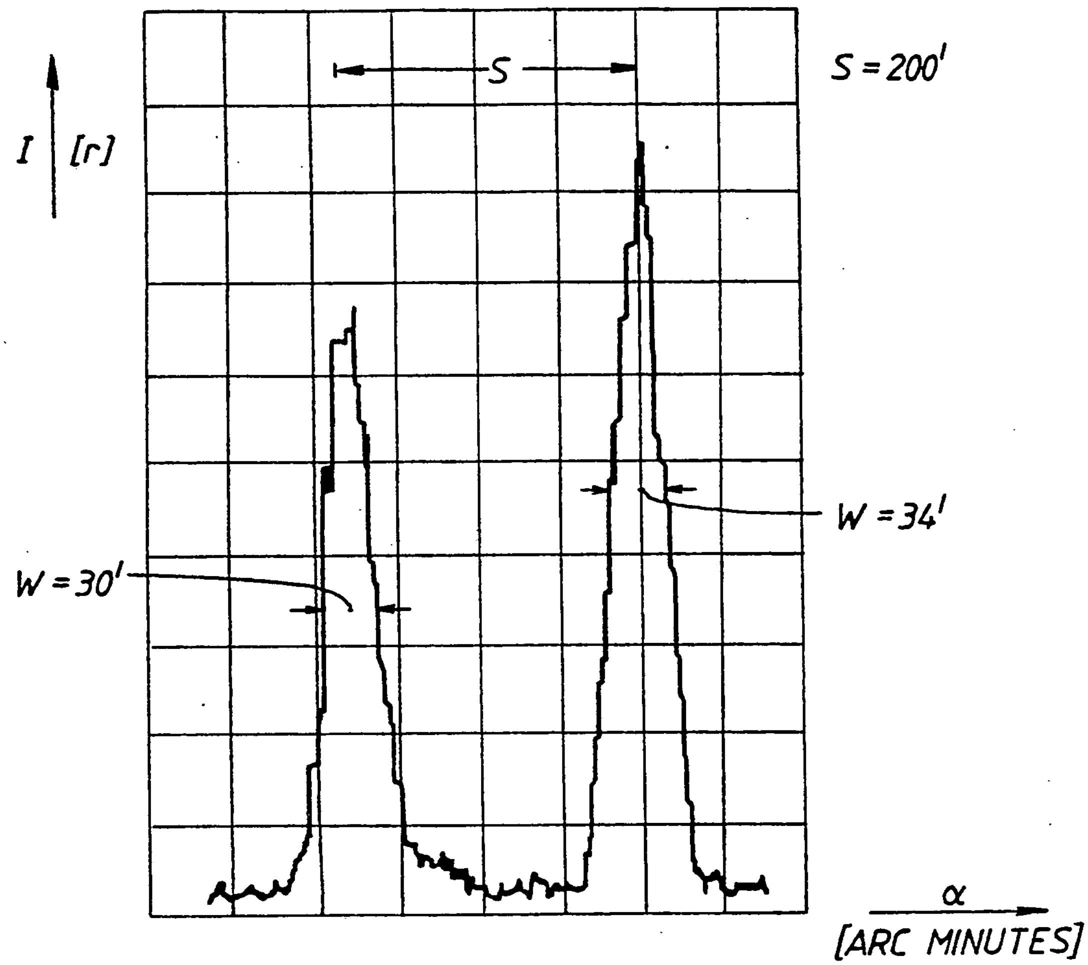

FIG. 4.

SPECIFICATION

Method and apparatus for inspecting a crystalline object

This invention relates to a method and apparatus for inspecting a crystalline object.

In DE-OS 32 36 109 (corresponding to G.B. 2 107 560 A) a method and an apparatus have been disclosed for determining the orientation of a crystal, wherein use is made of the Laue backscatter diagram of Roentgen or X-rays that are backscattered from the surface of the crystal. In this arrangement the X-ray and the detector centerline are oriented at an acute angle with respect to the surface. The detector output is processed using a computer to determine the angle of the main crystal axes.

The use of the Laue backscatter diagram of Roentgen rays is disadvantageous mainly because flaws in the interior of a crystalline object cannot be detected, as flaws are disclosed only in the surface zone (to some µm deep).

According to one aspect of the invention there is provided a method of inspecting a crystalline object wherein the object is irradiated with radiation from a gamma source, the intensity of gamma radiation diffracted by the object is detected, and a peak in the intensity is employed in an evaluation of the object.

According to another aspect of the invention there is provided an apparatus for use in inspecting a crystalline object, comprising a gamma source, a mount to receive an object to be irradiated by the gamma source, a detector to detect the intensity of radiation diffracted by the object, and an evaluation means coupled to the detector for use in evaluating a peak in said diffracted radiation as detected by the detector.

An embodiment of the present invention may eliminate or reduce the disadvantages inherent on the known method for inspecting mono-crystal objects.

The object may be inspected quantitatively as a whole, and the inspection may be entirely automated to preclude subjective influences.

A preferred form of the invention may be suitable as a production line inspection method for automated quality control (final inspection). The inspection may be made quantitatively and not merely qualitatively (superficially). The object may be totally penetrated by the radiation, and the inspection may represent genuine volume inspection.

For a better understanding of the invention and to show how it may be put into effect reference will now be made, by way of example, to the accompanying drawings in which:

Fig. 1 illustrates an inspection apparatus in the form of a gamma diffractometer according to the invention for performing the present method;

Fig. 2 illustrates a first single crystal or monocrystal turbine blade inspected in accordance with the present method in three predetermined inspection planes;

Fig. 2a illustrates the signals, including the reflection spacing, recorded as a result of inspecting the blade of Fig. 2 exhibiting a flawed crystal growth, whereby only the signals for the third plane are shown since the signals for the first and second inspection planes are similar to those of the third plane;

Fig. 3 illustrates a second single crystal blade inspected in accordance with the present method in three predetermined inspection planes which differ from those in Fig. 2;

Fig. 3a illustrates a sample of the signals recorded for each inspection plane as a result of inspecting the blade of Fig. 3 exhibiting a normal crystal growth; and

Fig. 4 illustrates a typical inspection log of the inspection of a single crystal test sample by means of a gamma diffractometer as taught herein, and showing a so-called "Verkippung" (or, literally translated, tilting) similar to the illustration of Fig. 2a, of the grain boundaries between two neighbouring grains in a test sample as shown in Fig. 2.

Fig. 1 shows a gamma diffractometer according to the present invention in which a radioactive source 1 is surrounded by a lead shield 2, for radiating gamma rays. A shutter or diaphragm 3 is arranged between an outlet of the lead shield 2 and a collimator 4. The opening and closing of the shutter 3 is controlled by a conventional first shutter drive 4 operatively connected, for example mechanically, to the shutter 3 as shown at 14". The first shutter drive 14 is connected by its control input 14' to a central processing unit 9 in a housing 11.

The collimator 4 is an elongate tublar member having a length of, for example 4 meters, for focussing the gamma rays. A second shutter or slot diaphragm 5 with a slot 5' is provided at the output end of the collimator 4. The slot 5' can be opened and closed in a predetermined timed sequence under the control of the central processing unit 9. This controls and operates the diaphragm 5 via a mechanical connection 15" to a slit shutter drive 15. The latter is connected by a control input 15' to the central processing unit 9 for opening and closing the slot 5' in synchronism with the operation of the first shutter 3. In this manner the gamma rays pass periodically through the slot 5' onto and through a test sample, such as a turbine blade 6 or 6'.

The central processing unit 9 also operates a display device including a display screen 10 and a recorder 17. The control input 12 to the display screen 10 is connected to the central processing unit 9, and so is the control input 17' to the recorder 17. These components 10 and 17 are of a conventional construction. For example, the screen 10 can be a cathode ray tube and the recorder 17 can be a graph recorder or so-called plotter.

The sample 6 is arranged on a turntable 7 rotating through an angle α. The angle of diffraction θ is sensed by a stationary detector 8. The signals from the detector 8, especially the relative radiation intensity reading I, measured for example in counts per sec. (S^{-1}), are processed and evaluated in the central processing unit 9. The central processing unit 9 controls a turntable drive motor 16, for example a stepping motor, operatively connected at

16" to the turntable 7 carrying the sample 6. A control input 16' to the motor 16 is connected to the central processing unit 9, which drives the stepping motor 16 in synchronism with the two shutter drives 14 and 15. The recorder 17 plots the intensity I as a function of the rotational angle α of the turntable 7.

Diffraction naturally occurs only in the presence of tilted grain "Verkippung" in a crystal. In other words, the results of the inspection are a measure of the purity of the single crystal sample, or the quality of the single crystal growing process. Two tilted grain boundaries 20 and 21 are indicated by dashed lines in the sample 6 of Fig. 2, representing a faulty crystal growth. The samples 6, 6' are placed on the turntable 7 in such different fixed positions that respective predetermined inspection planes a, b, and c will be irradiated by the beam of gamma rays. Inspection plane "a" in Fig. 2 is, for example, spaced 2 mm from the left end of the sample 6, whereas in Fig. 3 it is spaced 13 mm from the left end of sample 6'. Inspection plane "b" is spaced 54 mm in Fig. 2 and 51 mm in Fig. 3 from the left end of the blade. Inspection plane "c" is spaced 66 mm in Fig. 2 and 67 mm in Fig. 3 from the left hand end of the blade. Selection of the inspection plane will, for example, depend on the shape of the sample and on the primary stress zones of the sample.

In Fig. 2, the half peak value W (i.e. the width of the pulse, at one half its amplitude, in minutes of arc) for an actually tested turbine blade for plane "a" was 27' and 24' at the first and second grain boundaries 20 and 21 respectively. In plane "b" these values were 26' in both instances, and in plane "c" these values were 34' and 30' as also shown in Fig. 4. The respective reflection spacings S were 173' for plane "a", 186' for plane "b", and 200' for plane "c", also as shown in Fig. 4. Fig. 2a shows the reflection spacing S only once as a representative illustration. This spacing S is taken from peak to peak or from the leading edge of the first amplitude to the trailing edge of the second amplitude at the half peak value level, and indicates the magnitude of the tilting between two crystallites or grains. The respective values W and S are measured in arc minutes plotted along the abscissa in Fig. 2a, 3a and 4.

Fig. 2a shows a fundamental curve for a case where there are two crystallites (grains) situated in the sensed area, while Fig. 3a shows the single grain case (single grain boundary 22). The tilting is measured in minutes (') of arc.

The rotation α of the turntable 7 is also measured in arc minutes whereby the "cutting" width Δα of the inspection planes "a", "b", "c" corresponds to 1' as determined by the rotational speed of the turntable 7 and by the opening duration of the slot 5'. Both the rotational speed or stepping speed of the turntable 7 and the opening duration are determined by the central processing unit 9 in accordance with the respective programming stored in the central processing unit 9.

One or several samples can be inspected with the aid of a gamma diffractometer in a matter of several minutes up to about one half hour. The half peak width readings here are a measure of the quality of the crystallites, and the reflection spacing S in a certain crystal plane corresponds to, or represents, the tilting between two grains, being the reflection spacing at the lattice planes of the monocrystal grains. In this manner, conclusions regarding the quality of the crystal growth may be made. Thus, one can inspect the grain structure of, for example, monocrystal turbine blades, and the method and apparatus disclosed herein can be employed at a station for the automated final inspection of objects on a production line.

The embodiment of the present invention as here illustrated and described may be varied without departing from the basic teaching. More particularly, the inventive concept also embraces alternative measuring devices or inspection by passing gamma radiation through a test sample. Using other types of relative movement between the turntable and sample on the one hand and the detector on the other hand, than shown in Fig. 1, may be used so long as the spatial distribution of the radiation intensity (2θ-profile) can be determined. The planes in which the source of radiation and the detector are installed need not necessarily be the same, as long as a plurality of measurements allow the determination of one radiation projection based on radiation passing through the test sample.

All individual components of Fig. 1, including the radiation detector 8 and the central processing unit 9, may, as respective individual units, be of conventional construction.

Incidentally, θ is Bragg's diffraction angle. If the radiation emitted by the source 1 has a wave length λ, the respective equation is as follows $\lambda=2d \sin \theta$, wherein "d" is the spacing between two neighboring lattice planes.

Although the invention has been described with reference to specific example embodiments, it will be appreciated that it is intended to cover all modifications and equivalents within the scope of the appended claims.

CLAIMS

1. A method of inspecting a crystalline object wherein the object is irradiated with radiation from a gamma source, the intensity of gamma radiation diffracted by the object is detected, and a peak in the intensity is employed in an evaluation of the object.

2. A method according to claim 1, wherein the object is a monocrystal object.

3. A method according to claim 1 or 2, wherein the intensity of gamma radiation diffracted by the object is detected by a stationary detector.

4. A method according to any preceding claim, wherein the half width of said peak is employed in the evaluation of the object.

5. A method according to any preceding claim, wherein relative movement takes place between the object and the irradiating radiation. the intensity of the gamma radiation diffracted by the object being detected in dependence upon the relative alignments of the object and the irradiating radiation.

6. A m thod according to claim 5, wherein the

object rotates on a turntable.

7. A method according to any preceding claim, wherein in the presence of a plurality of crystallites or grains in the object, a plurality of intensity peaks are detected and the spacing thereof is evaluated to indicate the reflection spacing at the lattice planes of the monocrystal grains.

8. Method for inspecting monocrystal onbjects by radioactive irradiation, characterised in that the objects are roentgened with radiation from a gamma source, that the intensity profile of a diffracted reflection is picked up by a stationary detector and in that the half width of the reflection is measured.

9. An apparatus for use in inspecting a crystalline object, comprising a gamma source, a mount to receive an object to be irradiated by the gamma source, a detector to detect the intensity of radiation diffracted by the object, and an evaluation means coupled to the detector for use in evaluating a peak in said diffracted radiation as detected by the detector.

10. An apparatus according to claim 9, wherein the gamma source is within a shield is followed by a collimator.

11. An apparatus according to claim 9 or 10, and comprising means for effecting the periodic emergence of a focussed beam onto the object.

12. An apparatus according to any of claims 9 to 11, wherein said detector is stationary.

13. An apparatus according to any of claims 9 to 12, wherein said mount comprises a turntable.

14. An apparatus according to claim 13, wherein the detector is provided with means for recording the detected radiation intensity as a function of the rotational angle of the object with the turntable.

15. An apparatus according to claim 10, or any of claims 11 to 14 when appended to claim 10, wherein the collimator is of tubular construction and has at its source end a shutter or diaphragm, and at its other end a shutter or slotted diaphragm.

16. Apparatus for implementing the method of claim 8, characterised in that as a diffractometer, it contains a radioactive gamma source within a shield followed by a collimator, with means for the temporary emergence of a focussed beam onto the object under inspection, said object being arranged on a rotary table associated with a stationary radiation detector and a control and/or evaluation device.

17. A method for inspecting a crystalline object, substantially as hereinbefore described with reference to Figures 1 to 4 of the accompanying drawings.

18. An apparatus for use in inspecting a crystalline object, substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

19. A method or an apparatus according to any preceding claim, when employed for inspecting the grain structure of monocrystal turbine blades.

20. A method or an apparatus according to any preceding claim, when employed at a station for the automated final inspection of objects on a production line.

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